A METHOD OF MEASURING EJECTION VELOCITIES DURING EXPERIMENTAL IMPACT EVENTS.

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Velocities of material ejected from impact-cratering events remain poorly quantified. Measurements of ejecta velocities have been made for explosion craters[1,2] and spallation fragments from collisional disruptions,[3,4,5,6] but the spectra of ejection velocities from impacts into weak media have not yet been described rigorously. Oberbeck and Morrison[7] performed experiments using the NASA Ames Vertical Gun, sand targets, and a "plume dissector" to break ejecta curtains into "packets," but this method might have interfered with the ballistics of the ejecta, raising some question as to its accuracy.

We have developed a technique for measuring the velocities of individual fragments of ejecta from craters forming in media as fine-grained as blasting sand. This method also has the potential for use in determining the times of crater growth in extremely fine-grained media, although in this latter case the individual grains are not detectable. This contribution describes the method and apparatus used to collect these ejection-velocity data.

Background — Andrews[1] and Piekutowski *et al.*[2] photographed and measured the velocities of ejecta from small, explosion craters with a stroboscopic technique. Floodlights and cylindrical lenses were used to generate a "sheet" of light through the explosive charge and perpendicular to the target surface. This sheet of light was also oriented such that it was parallel to the film plane of a camera, insuring that only those ejecta in the film plane were illuminated. The stroboscopic effect was generated by a rotating shutter placed in the film plane; the strobe rate was varied by changing the speed of rotation of the shutter. The parabolic trajectories of the fragments, coupled with the known time between illuminations, then yielded the angle and speed of ejection of those fragments.

The method described here is simply an updated version of the technique used by Andrews and Piekutowski *et al.* ,with minor modifications (Fig.1). Specifically, the major differences are in illumination and photography. In this case, illumination is provided by an infrared laser whose output is modulated by a waveform generator, obviating the need for the rotating shutter. A cylindrical lens, however, is still used to create the sheet of light. The second major difference between this and the earlier apparatus is in the cameras. The CCD camera used here is much more sensitive than the film to which Andrews and Piekutowski *et al.* were limited. This camera permits extremely short flashes with the laser, whose wavelength is near the peak sensitivity of the CCD chip.

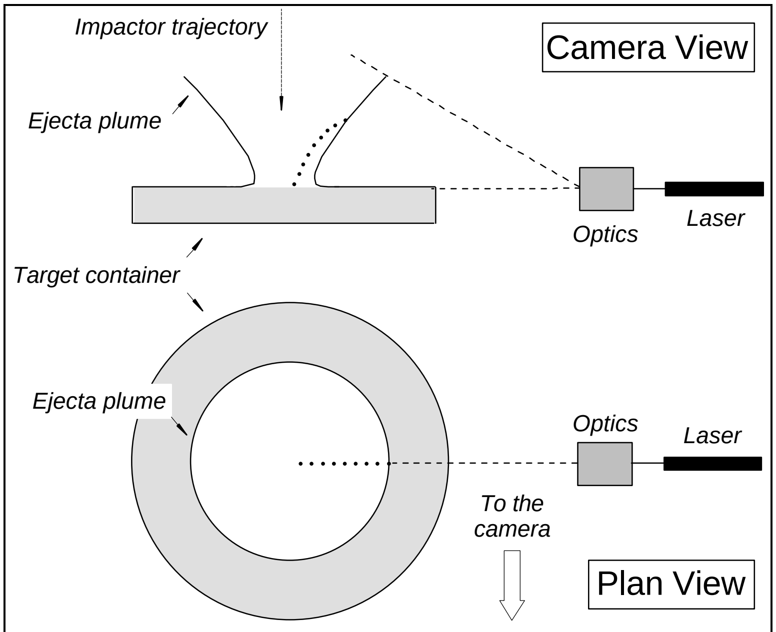

Figure 1. Simplified diagram of the system used to measure ejection velocities from small impact craters. The laser, strobed at a programmed rate with a waveform generator, illuminates individual fragments of ejecta, schematically illustrated here as a series of dots inside the ejecta plume. The camera is not shown.

The data-collection sequence is initiated by the signal to fire the gun and controlled by a computer. It fires the gun after the CCD is cleared, and the camera's shutter is opened. A signal generated by the impact flash via a photodetector begins the programmed sequence of laser bursts. Ejecta in flight are then recorded as a series of "dotted parabolas" (Fig.2). Measurement of the distances between the stroboscopic images of individual grains and the known flash rate of the laser then yields the point of origin at the target surface and the ejection velocity for each measured fragment.

Discussion — The two principal factors currently limiting the use of this system are the impact flash generated at high impact velocities and the size of the individual fragments of ejecta. While the impact flash is useful for triggering purposes, at higher velocities it is so extreme as to overwhelm much of the earliest ejecta. This is a difficult problem, and might be surmountable only by using a much more powerful laser whose output would, in turn, overwhelm the self-luminosity of the fragments. The smaller fragments are currently limited in their usefulness as a target medium insofar as the number of photons reflected to the camera is proportional to the cross-sectional area of the fragment. Thus, the trajectories of fine-grained sand will be difficult to measure without a fast telephoto lens. Fine-grained material is useful, however, in evaluating the temporal evolution of the ejecta plume's morphology (Fig. 3)

Initial results of velocity determinations for ejecta from craters formed in coarse-grained sand (similar to that in Fig. 2) are presented elsewhere in this volume.[8]

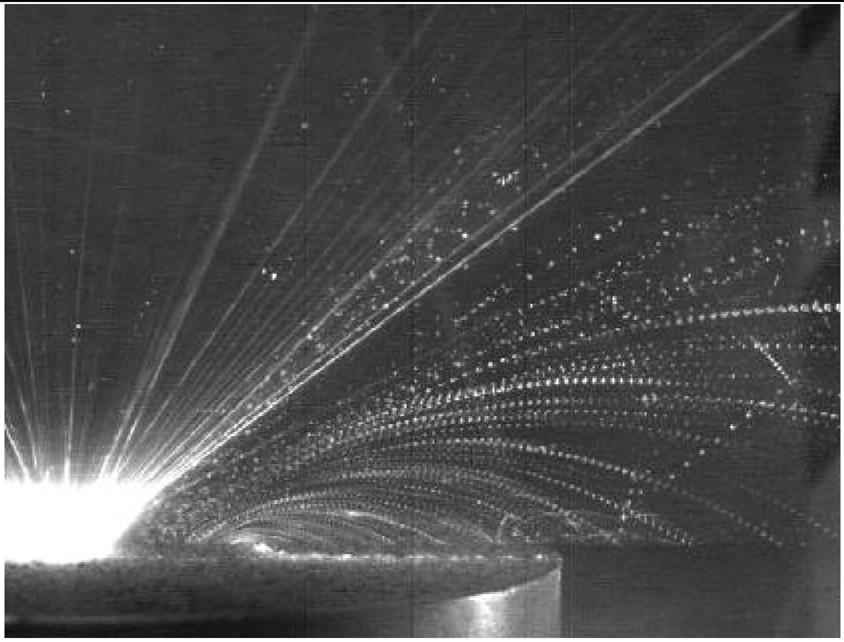

Figure 1. Example of a photograph of ejecta in flight taken with the laser/CCD system. A 3.18-mm glass sphere impacted a target of blasting sand at a velocity of 1.24 km s^{-1}, creating the bright flash, luminous ejecta (the solid streaks radial to the impact point), and an 11-cm crater. The laser is illuminating the scene from the right. Note that the flash rate (illumination in 100 μs bursts, every 2 ms) was too high for the slowest ejecta, which appear as small, solid parabolas. The isolated fragments cutting across the parabolic trajectories in the right of the image are ricochets from the lexan box that houses the laser and optics. Note also the "saltating" particles on the right edge of the target's surface. The target container is 27 cm in diameter.

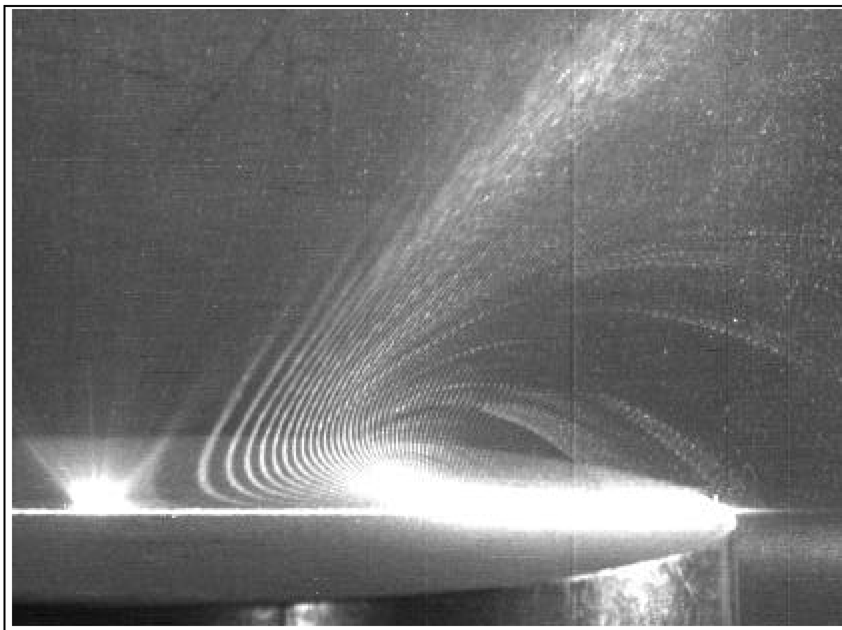

Figure 3. Except for the finer sand used here as a target medium, the conditions of this impact were virtually identical to that in Fig. 2. As a result, the outline of the ejecta plume is the dominant form in this photograph. The strobing rate of the laser was constant in this photograph, and demonstrates how the rate of plume (and crater) growth decreases with time.

References —**1** Andrews R. J. (1977) *Impact Explos Cratering* (D. J. Roddy *et al.*, eds.), pp. 1089-1100. Pergamon Press, New York. **2** Piekutowski A. J. *et al.* (1977) *Proc. 12th Internat. Congress High-Speed Photog.*, pp. 177-183. Soc. Photo-Optical Instr. Engin., Bellingham, WA. **3** Fujiwara A. and Tsukamoto A. (1980) *Icarus* **44**, 142-153. **4** Nakamura A. and Fujiwara A. (1991) *Icarus* **92**, 132-146. **5** Ryan E. V. and Davis D. R. (1991) Laboratory impact experiments: Ejecta velocity distributions. *Lunar Planet. Sci. XXII*, pp. 1153-1154. Lunar and Planetary Institute, Houston, TX. **6** Nakamura A. *et al.* (1992) *Icarus* **100**, 127-135. **7** Oberbeck V. R. and Morrison R. H. (1976) *PLSC. 7*, 2983-3005. **8** Berthoud L. (1997), this volume.